TITLE OF THE INVENTION

NOVEL BREAKERS OF ADVANCED GLYCATION ENDPRODUCTS

CROSS REFERENCE TO RELATED APPLICATIONS

The present invention is a continuation-in-part of application Serial No. 09/800,976, filed 8 March 2001, which is a continuation-in-part of application Serial No. 09/543,703, filed 5 April 2000, which is related to provisional application Serial No. 60/127,835, filed 5 April 1999, and the present application is a continuation-in-part of application Serial No. 09/626,859, filed 27 July 2000, which is a continuation-in-part of application Serial No. 09/543,703 filed 5 April 2000 which is related to application Serial No. 60/127,835 filed 5 April 1999, and the present application is a continuation-in-part of application Serial No. 09/559,913 filed 28 April 2000 which is related to application Serial No. 60/131,675 filed 29 April 1999, all of which are incorporated herein by reference and all of which are claimed as priority documents.

BACKGROUND OF THE INVENTION

Glucose and other reducing sugars react and bind covalently to proteins, lipoproteins and DNA by a process known as non-enzymatic glycation. Glucose latches onto tissue proteins by coupling its carbonyl group to a side-chain amino group such as that found on lysine. Over time, these adducts form structures called advanced glycation endproducts (AGEs) (protein-aging). These cross-linked proteins stiffen connective tissue and lead to tissue damage in the kidney, retina, vascular wall and nerves. The formation of AGEs on long-lived connective tissue accounts for the increase in collagen cross-linking that accompanies normal aging which occurs at an accelerated rate in diabetes.

The publications and other materials used herein to illuminate the background of the invention or provide additional details respecting the practice, are incorporated by reference, and for convenience are respectively grouped in the appended List of References.

Advanced glycation endproducts (AGEs) have been implicated in the pathogenesis of a variety of debilitating diseases such as diabetes, atherosclerosis, Alzheimer's and rheumatoid arthritis, as well as in the normal aging process. Most recent researchers confirm a significant role of the accumulation of AGE cross-links in promoting the decreased cardiovascular compliance of aging (Asif et al., 2000; Vaitkevicius et al., 2001). The process of AGE formation

on arterial wall matrix proteins may be related to the development of atherosclerosis in many different ways, such as generation of free radicals (ROS) during the glycation process, inhibition of a normal network formation in collagen by AGE accumulation (Brownlee, 1994), and increased adhesion of monocytes (Gilcrease and Hoover, 1992).

The hallmark Diabetes Control and Complications Trial (DCCT) demonstrated that normalization of blood glucose control by intensive insulin therapy reduces the risk of development of diabetic complications (Diabetes Control and Complications Trial Research Group, 1993). However, intensive insulin therapy neither prevents nor cures complications. Thus, a large number of patients still are prone to develop vascular complications, and additional pharmacological approaches to prevent these complications are desirable.

More recently, several promising therapeutic drugs that could inhibit or break the AGE crosslinks in tissues and cells, and thus prevent these complications, have been reported. Both inhibitors of AGE formation and AGE-breakers not only may have a beneficial effect in reducing these complications, AGE-breakers may cure the disease by removing AGEs from damaged tissues and cells.

Aminoguanidine is a prototype of "glycation inhibitors". These inhibitors may find therapeutic use in preventing diabetic complications and in delaying normal aging. In addition to aminoguanidine, a large number of much more potent inhibitor compounds have been introduced by us and others recently (Rahbar et al., 1999; Rahbar et al., 2000a; Rahbar et al., 2000b; Kochakian et al., 1996; Khalifah et al., 1999; Soulis et al., 1999; Forbes et al., 2001).

Investigation for selectively cleaving and severing the existing AGE-derived cross-links on tissue proteins by pharmacological strategies has been started more recently. N-phenacylthiazolium bromide (PTB) and ALT 711 have been reported to break AGE cross-links *in vitro* and *in vivo*. The introduction of PTB, the first AGE-breaker which was introduced in 1996, generated excitement among the researchers in this field. However, PTB was used at nonphysiological concentrations (10-30 mM), and was observed to degrade rapidly *in vitro* (Thornalley and Minhas, 1999). Additionally, contrasting results were observed on diabetic rats treated with PTB used at the same concentration of 10 mg/kg daily (Cooper et al., 2000; Oturai et al., 2000). Although the more stable PTB derivative ALT711 has demonstrated AGE-breaking activities both *in vitro* and *in vivo* (Vasan et al., 1996; Rahbar et al., 1999), a recent report by

Yang et al. (2000) found that ALT711 was not effective in cleaving crosslinks formed in skin and tail collagen of diabetic rats.

The Diabetes Control and Complications Trial (DCCT), has identified hyperglycemia as the main risk-factor for the development of diabetic complications (Diabetes Control and Complications Trial Research Group, 1993). Ever increasing evidence identifies the formation of advanced glycation endproducts (AGEs) as the major pathogenic link between hyperglycemia and the long-term complications of diabetes, namely nephropathy, neuropathy and retinopathy (Makita et al., 1994; Koschinsky et al., 1997; Makita et al., 1993; Bucala et al., 1994; Bailey et al., 1998).

Nonenzymatic glycation is a complex series of reactions between reducing sugars and amino groups of proteins, lipids and DNA, which lead to browning, fluorescence, and cross-linking (Bucala and Cerami, 1992; Bucala et al., 1993; Bucala et al., 1984). The reaction is initiated with the reversible formation of a Schiff's base, which undergoes a rearrangement to form a stable Amadori product. Both the Schiff's base and Amadori product further undergo a series of reactions through dicarbonyl intermediates to form advanced glycation endproducts (AGEs).

In human diabetic patients and in animal models of diabetes, these nonenzymatic reactions are accelerated and cause accumulation of glycation products on long-lived structural proteins such as collagen, fibronectin, tubulin, lens crystallin, myelin, laminin and actin, and in addition on several other important biological molecules such as hemoglobin, albumin, LDL-associated lipids and apoprotein. Most recent reports indicate that glycation inactivates metabolic enzymes (Yan and Harding, 1999). The structural and functional integrity of the affected molecules, which often have major roles in cellular functions, become perturbed by these modifications with severe consequences on affected organs such as kidney, eye, nerve, and micro-vascular vessels (Boel et al., 1995; Silbiger et al., 1993; Vlassara et al., 1995; Horie et al., 1997; Matsumoto et al., 1997; Soulis-Liparota et al., 1991; Bucala, 1997; Bucala and Rahbar, 1998; Park et al., 1998). Recent reports indicate glycation to affect metabolic enzymes, high-density lipoproteins and IgG molecules (Yan and Harding, 1999; Lapolla et al., 2000; Lucey et al., 2000; Schalkwijk et al., 1998; Hedrick et al., 2000). The glycation-induced change of immunoglobin G is of particular interest. Recent reports of glycation of Fab fragment of IgG in diabetic patients suggest that immune deficiency observed in these patients may be explained by

this phenomenon (Lapolla et al., 2000). Furthermore, an association between IgM response to IgG damaged by glycation and disease activity in rheumatoid arthritis have been reported recently (Lucey et al., 2000). Also, impairment of high-density lipoprotein function by glycation has been reported recently (Hedrick et al., 2000).

Direct evidence indicating the contribution of AGEs in the progression of diabetic complications in different lesions of the kidneys, the rat lens, and in atherosclerosis has been recently reported (Vlassara et al., 1995; Horie et al., 1997; Matsumoto et al., 1997; Soulis-Liparota et al., 1991; Bucala, 1997; Bucala and Rahbar, 1998; Park et al., 1998). Several lines of evidence indicate the increase in reactive carbonyl intermediates (methylglyoxal, glyoxal, 3-deoxyglucosone, malondialdehyde, and hydroxynonenal) is the consequence of hyperglycemia in diabetes. This "carbonyl stress" leads to increased modification of proteins and lipids, followed by "oxidative stress" and tissue damage (Baynes and Thorpe, 1999; Onorato et al., 1999; McLellan et al., 1994).

Methylglyoxal (MG) has recently received considerable attention as a common mediator to form AGEs. In patients with both insulin-dependent and non-insulin dependent diabetes, the concentration of MG was found to be increased 2-6 fold (Phillips and Thornalley, 1993; Beisswenger et al., 1998). Furthermore, MG has been found not only as the most reactive dicarbonyl AGE-intermediate in cross-linking of proteins, a recent report has found MG to generate reactive oxygen species (ROS) (free radicals) in the course of glycation reactions (Yim et al., 1995).

An intricate relationship between glycation reactions and "oxidative stress" has been postulated (Baynes and Thorpe, 1999). Nature has devised several humoral and cellular defense mechanisms to protect tissues from deleterious effects of "carbonyl stress" and accumulation of AGEs. These include the glyoxylase system (I and II) and aldose reductase catalyze the deglycation of methylglyoxal (MG), the most common reactive intermediate of AGEs (Phillips and Thornalley, 1993; Beisswenger et al., 1998; Yim et al., 1995), to D-lactate. Additionally, a novel class of enzymes found in *Aspergillus*, called amadoriases, was found to catalyze the deglycation of Amadori products (Takahashi et al., 1997). Furthermore, several AGE-receptors have been characterized on the surface membranes of monocyte, macrophage, endothelial, mesangial and hepatic cells. One of these receptors, RAGE, a member of the immunoglobulin superfamily, has been found to have a wide distribution in tissues (Schmidt et al., 1994; Yan et

al., 1997). MG binds to and irreversibly modifies arginine and lysine residues in proteins. MG modified proteins have been found as ligands for the AGE receptor (Westwood et al., 1997) indicating that MG modified proteins are analogous (Schalkwijk et al., 1998) to those found in AGEs. The discovery of various natural defense mechanisms against glycation and AGE formation suggests an important role of AGEs in the pathogenesis of vascular and peripheral nerve damage in diabetes. Most recently, the effects of MG on LDL have been characterized *in vivo* and *in vitro* (Bucala et al., 1993).

Lipid peroxidation of polyunsaturated fatty acids (PUFA), such as arachidonate, also yield carbonyl compounds. Some are identical to those formed from carbohydrates (Al-Abed et al., 1996), such as MG and glyoxal (GO), and others are characteristic of lipid, such as malondialdehyde (MDA) and 4-hydroxynonenal (HNE) (Requena et al., 1997). The latter of the carbonyl compounds produce lipoxidation products (Al-Abed et al., 1996; Requena et al., 1997). A recent report emphasizes the importance of lipid-derived MDA in the cross-linking of modified collagen and in diabetes mellitus (Slatter et al., 2000). A number of fluorescent and non-fluorescent AGE compounds that are involved in protein cross-linking have been characterized (Baynes and Thorpe, 1999) (see Table 1). In addition to glucose derived AGE-protein cross-links, AGE cross-linking also occurs between tissue proteins and AGE-containing peptide fragments formed from AGE-protein digestion and turnover. These reactive AGE-peptides, now called glycotoxins, are normally cleared by the kidneys. In diabetic patients, these glycotoxins react with the serum proteins and are a source for widespread tissue damage (Schmidt et al., 1994). However, detailed information on the chemical nature of the cross-link structures remains unknown. The cross-linking structures characterized to date (Table 1), on the basis of chemical and spectroscopic analyses, constitute only a small fraction of the AGE-cross-links which occur *in vivo*, with the major cross-linking structure(s) still unknown. Recently, a novel acid-labile AGE-structure, N-omega-carboxymethylarginine (CMA), has been identified by enzymatic hydrolysis of collagen, and its concentration was found to be 100 times greater than the concentration of pentosidine (Iijima et al., 2000), and has been assumed to be a major AGE-cross-linking structure (Yan et al., 1997).

TABLE 1

CURRENT LIST OF AGEs IDENTIFIED IN TISSUE

PROTEINS AND IN VITRO GLYCATION EXPERIMENTS (Baynes and Thorpe, 1999)

Carboxymethyllysine (CML)	
Carboxyethyllysine (CEL)	
Carboxymethylarginine (CMA)	
Pentosidine	
Pyralline	
Crosslines (A, B)	
Glyoxallysine dimers (GOLD), Imidazolium salts	
Methylglyoxal-lysine dimers (MOLD), Imidazolium salts	
Imidazolones and dehydroimidazolones	3-Deoxyglucosone-Arginine MGO-Arginine
Pyrrolopyrridinium	
Arginine – Lysine dimer (ALS)	
Arginine Pyridinium	
Cypentodine	
Piperidinedinone enol	
Vesperlysine	
MRX	

SUMMARY OF THE INVENTION

Seven compounds have been found which are active in breaking AGE-protein cross-links. These compounds are: 1,4-benzene-bis[4-methyleneaminophenoxyisobutyric acid] (LR102); 4-[(3,5-dichlorophenylureidophenoxyisobutyryl]-4-aminobenzoic acid (LR99); L-bis-[4-(4-chlorobenzamidophenoxyisobutyryl)cystine] (LR20); 4-(3,5-dichlorophenylureido)phenoxyisobutyryl-1-amidocyclohexane-1-carboxylic acid (LR23); methylene bis [4,4'-(2-chlorophenylureidophenoxyisobutyric acid)] (LR90); 5-aminosalicylic acid (5-ASA) (also referred to herein as SMR-5); and metformin (also referred to herein as SMR-12).

In one aspect of the invention, these AGE-breaking compounds are used to break glycation endproducts or cross-linked proteins in an organism by administering to an organism an effective amount of one or more of the AGE-breakers.

In a second aspect of the invention, the deleterious effects of aging in an organism are reversed by administering an effective amount of an AGE-breaker to the organism.

In a third aspect of the invention, complications resulting from diabetes in an organism are reversed by administration of an effective amount of an AGE-breaker to the organism.

In further aspects of the invention, the progress of disease in a patient, wherein the disease can include rheumatoid arthritis, Alzheimer's disease, uremia, neurotoxicity, or atherosclerosis, is reversed by administration of an effective amount of an AGE-breaker to the patient.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1A shows the cleavage of cross-linked collagen-AGE-BSA by LR20, LR23 and LR90. AGE represents collagen-AGE-BSA in the absence of any AGE-breaker.

Figure 1B shows the dose dependent AGE-breaking activity of 5-ASA by measuring cleavage of cross-linked collagen-AGE-BSA. AGE represents collagen-AGE-BSA in the absence of 5-ASA.

Figure 1C shows the cleavage of cross-linked collagen-AGE-BSA by LR102, 5-ASA (SMR-5), and metformin (SMR-12). AGE represents collagen-AGE-BSA in the absence of any AGE-breaker.

Figures 2A-D show the solubility of collagen treated with novel AGE-breakers (LR20, LR23, LR99 and LR102) in weak acetic acid. Values are means ± S.D. of 2-3 collagen samples. *P* values were calculated using unpaired Student's *t*-test. For each figure * indicates $P<0.05$ vs. non-diabetic control and ** indicates $P<0.05$ vs. diabetic control.

Figures 3A-D show the results of pepsin digestion of collagen treated with novel AGE-breakers (LR20, LR23, LR99 and LR102). Values are means ± S.D. of 2-3 collagen samples. *P* values were calculated using unpaired Student's *t*-test. For each figure * indicates $P<0.05$ vs. non-diabetic control and ** indicates $P<0.05$ vs. diabetic control.

Figures 4A-D show the results of papain digestion of collagen treated with novel AGE-breakers (LR20, LR23, LR99 and LR102). Values are means ± S.D. of 2-3 collagen samples.

P values were calculated using unpaired Student's *t*-test. For each figure * indicates $P<0.05$ vs. non-diabetic control and ** indicates $P<0.05$ vs. diabetic control.

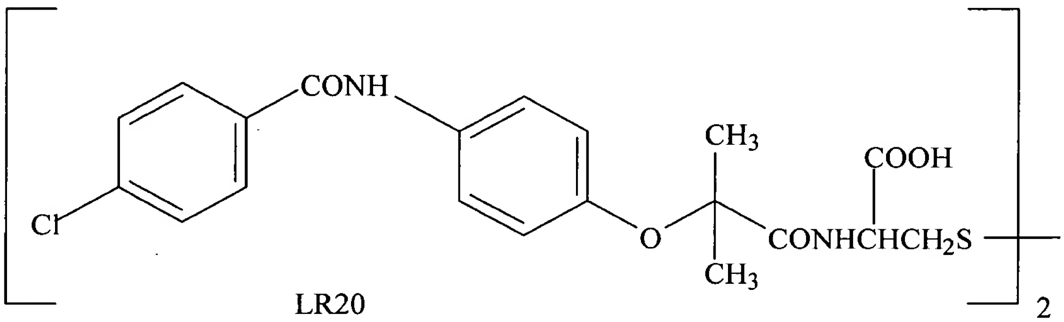
Figures 5A-C show the effect of 5-ASA (SMR-5) treatment on rat tail collagen. Figure 5A shows solubility in weak acid, figure 5B shows the results with pepsin digestion, and Figure 5C shows the results with papain digestion. Values are means ± S.D. of 2-3 collagen samples. *P* values were calculated using unpaired Student's *t*-test. For each figure * indicates $P<0.05$ vs. non-diabetic control and ** indicates $P<0.05$ vs. diabetic control.

Figure 6 shows the results of treating crosslinked IgG-AGE on rat RBCs with novel AGE-breakers (5-ASA (SMR-5) and LR102). Values are means ± SEM of three separate determinations.

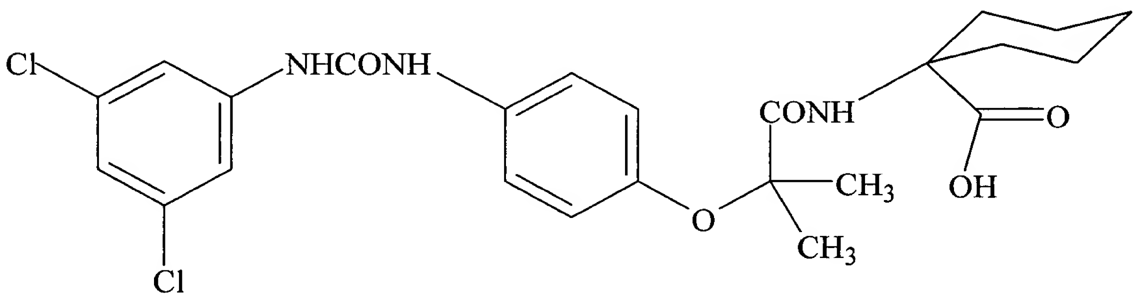
DETAILED DESCRIPTION OF THE INVENTION

We have reported a new class of compounds, aryl (and heterocyclic) ureido and aryl (and heterocyclic) carboxamido phenoxyisobutyric acids, as inhibitors of glycation and AGE formation (Rahbar et al., 1999; Rahbar et al., 2000a). A number of highly effective inhibitors were among the 92 compounds tested (Rahbar et al., 1999; Rahbar et al., 2000a). These were selected for *in vivo* experimentation in streptozotocin (STZ) induced diabetic rats. Recent discoveries of novel compounds, such as phenacylthiazolium bromide (PTB) (Vasan et al., 1996) and ALT 711 (Wolffenbuttel et al., 1998), which are able to cleave selectively the established AGE-protein cross-links *in vitro* and *in vivo*, have been exciting (Cooper et al., 2000). Furthermore, ALT 711 was reported to reverse the age-related increase of myocardial stiffness *in vivo* in aging dogs and monkeys (Asif et al., 2000; Vaitkevicius et al., 2001). Disclosed here are the results of an investigation of AGE-breaking properties of a number of compounds we have recently developed as potent inhibitors of glycation and AGE-formation (Rahbar et al., 1999; Rahbar et al., 2000a). Using a specific ELISA technique and other *in vitro* assays for screening our compounds, seven compounds have been found to be powerful AGE-cross-link breakers. These compounds are: 1,4-benzene-bis[4-methyleneaminophenoxyisobutyric acid] (LR102); 4-[(3,5-dichlorophenylureidophenoxyisobutyryl]-4-aminobenzoic acid (LR99); L-bis-[4-(4-chlorobenzamidophenoxy isobutyryl) cystine (LR20); 4-(3,5-dichlorophenylureido)-phenoxyisobutyryl-l-amidocyclohexane-1-carboxylic acid (LR23); methylene bis [4,4'-(2-

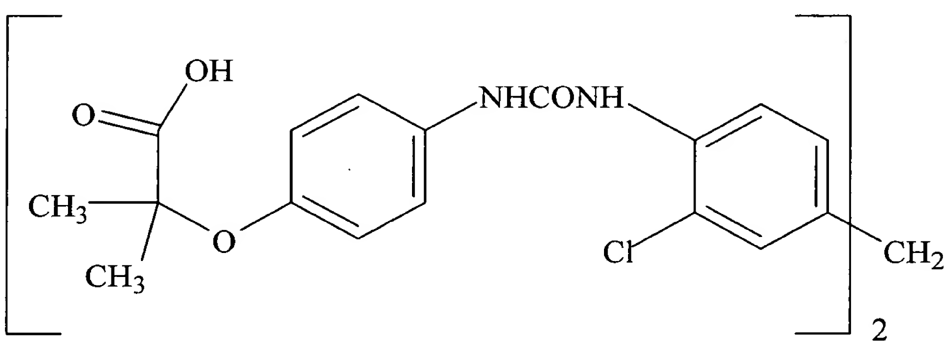
chlorophenylureidophenoxyisobutyric acid)] (LR90); 1,1-dimethylbiguanide (metformin); and 5-aminosalicylic acid (5-ASA). The structures of LR20, LR23, LR90, LR99 and LR102 are:



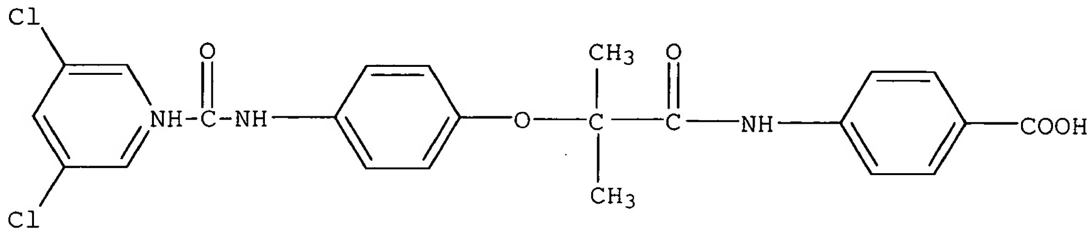
LR20



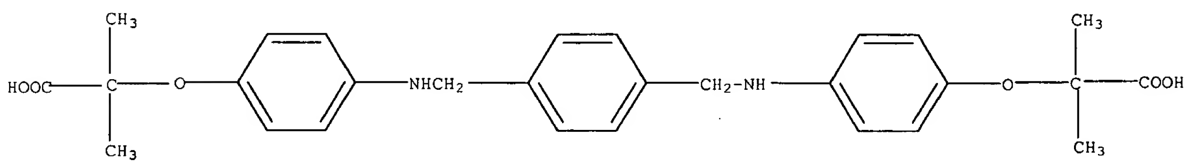
LR23



LR90



LR99



LR102

As described in the Examples below, compounds LR20, LR23, LR90, LR99 and LR102 in this study were each used at 0.1-10 mM final concentration and were very effective AGE-breakers as demonstrated in Figures 1A and 1C. 5-ASA was used at 20 μM, 50 μM and 1 mM and demonstrated dose dependent AGE-breaking activities as shown in Figure 1B. This characteristic of 5-ASA may be one of the reasons this drug is effective in the treatment of "ulceritis colitis" and Crohn disease. Furthermore, this drug may have beneficial effects in reversing AGE-cross-links in rheumatoid arthritis where accumulation of AGE in collagen and an immunological response to IgG damaged by glyoxidation (AGE-IgG) have been reported recently (Lucey et al., 2000). Finally, 5-ASA may have some effects on reducing damage of the β-amyloid contents of Alzheimer plaques.

Metformin, a highly popular drug for the treatment of Type 2 diabetes, was found by us to be a potent inhibitor of glycation (Rahbar et al., 2000b). In the Examples below evidence is presented that metformin is also a moderate AGE-breaker.

The mechanism of action of our AGE-breaker compounds is yet to be discovered. However, since these compounds release BSA from the preformed AGE-BSA-Collagen complex as detected immunochemically by ELISA, we assume these AGE-breakers are able to chemically

cleave α-diketones by breaking the chemical bond between the carbonyl groups, similar to the PTB mechanism of action (Ulrich and Zhang, 1997).

The present invention is further detailed in the following Examples, which are offered by way of illustration and are not intended to limit the invention in any manner. Standard techniques well known in the art or the techniques specifically described below are utilized.

Example 1

Compounds and Materials

LR20, LR23, LR90, LR99 and LR102 were synthesized in our laboratory. These compounds are easily synthesized by those of skill in the art. These are among the 102 compounds we have developed as inhibitors of glycation and AGE formation (Rahbar et al., 1999; Rahbar et al., 2000a). Metformin (1,1-dimethylbiguanide) and 5-aminosalicylic acid (5-ASA) were purchased from Sigma.

Rat tail-tendon-collagen coated 96 well microtiter plates were purchased from Biocoat (Collaborative Research, Bedford, MA) and used according to the manufacturer's instructions. Streptozotocin, rabbit polyclonal anti-BSA antibody, rat-tail-collagen (type VII, acid soluble), bovine serum albumin, glucose, human IgG, rabbit-anti-rat IgG, anti-human IgG, methylglyoxal, pepsin, papain, 1-propanol, chloramine-T trihydrate, EDTA, PMSF, iodoacetamide, benzamidine hydrochloride, p-dimethylamino-benzaldehyde, trans-4-hydroxyproline (crystalline), Thioflavin-T (ThT) and Congo Red (CR) were obtained from Sigma Chemical co. (St. Louis, MO). The horseradish peroxidase-linked goat anti-rabbit IgG and hydrogen peroxide substrate ABTS (2,2'-azino-di-3-ethylbenzthiazoline sulfonic acid) as chromogen was purchased from Zymed (San Francisco, CA). Perchloric acid (70% ACS), glacial acetic acid (99.5%, ASA) and 12 N hydrochloric acid were from J.T. Baker (Phillipsburg, NJ). β-amyloid (1-40) peptide was from Bachem (Torrance, CA). Amicon filters (cut-off 10,000 Da) were obtained from Amicon (Beverly, MA). Spectra/Por CE dialysis membrane (molecular cut-off 1000 Da) was from Spectrum Inc. (Houston, TX). All other reagents used were of analytical grade.

Example 2

Evaluation of Cleavage of Glycated BSA by AGE-breaker Compounds

In vitro evaluation of the ability of the AGE-breaker compounds to cleave and break cross-linking of glycated BSA (AGE-BSA) (prepared as described (Rahbar et al., 1999)) to the rat-tail-tendon-collagen was by a special ELISA (Vasan et al., 1996). The rat-tail-tendon-collagen coated plates were first blocked first with 300 μL of Superblock blocking buffer (Pierce Chemicals, Rockford, IL) for one hour. The blocking solution was removed from the wells by washing the plates twice with PBS-0.05% Tween 20 (PBS-T) using a Dynatech ELISA-plate washer. Cross-linking of various concentrations of AGE-BSA (0, 0.01, 0.05, 0.1, 0.25, 0.50, and 1.0 μg per well) to rat-tail-collagen coated plates was performed without the testing compound, and the plates were incubated for 5 hours at 37°C. After washing the wells three times with PBS-T to remove the unattached AGE-BSA, test concentrations of the compound (50 μL/well) dissolved in PBS were added to wells in triplicate and incubation continued at 37°C overnight. After washing with PBS-T, the amount of BSA remaining attached to the tail collagen plate was then quantified by addition of rabbit anti-BSA polyclonal antibodies (50 μL/well) for 1 hour at 37°C. The wells were then washed three times with PBS-T and developed with the chromogenic substrate ABTS (100 μL/well). Absorbance was measured at 410 nm in microplate reader (BioRad, Hercules, CA).

The percentage breaking activity is calculated by the following formula:

100 x [(A_{410}, PBS control) - (A_{410}, AGE-breaker compound)]/[$A_{410,}$ PBS control].

Example 3

Disaggregation of β-Amyloid Fibrils *in Vitro*

AGE-modified β-amyloid peptide, prepared by the incubation of glucose with β-AP (amino acids 1-40, from Bachem, Torrance, CA), has been shown to initiate efficiently the aggregation and polymerization of β-AP into amyloid fibrils *in vitro*.

Originally this assay was used for PTB (Al-Abed et al., 1999) and showed that PTB at 20 mM concentration disaggregates β-amyloid fibrils that have been aggregated in this manner. In the original version of this assay, AGE-β-amyloid had to be radioiodinated and then dialyzed to remove the unincorporated radioiodine ^{125}I and separated by SDS-PAGE in a 4-10% gradient gel which makes this assay very cumbersome.

In a new version of this assay, Bucala and Callaway (Bucala, personal communication; Tjernberg et al., 1999) have proposed the following approaches to demonstrate the disaggregation of the AGE-β-amyloid peptide by the AGE-breaker compounds. The Thioflavin T (ThT) fluorescence assay and Congo Red binding assay are based on the fact that Congo Red and ThT undergo characteristic spectral alteration on binding to a variety of amyloid fibrils (β-sheet conformation) that do not occur on binding to the precursor polypeptides and monomers. Both dyes have been adapted to *in vitro* measurements of amyloid fibril formation and quantification. ThT binding to β-amyloids gives rise to a large fluorescence excitation spectral shift that allows selective excitation of the amyloid fibril bound ThT (Tjernberg et al., 1999). In the present study, we have investigated the disaggregation of both native (unmodified) and glycated β-amyloid (1-40) peptide by the AGE-breaker compounds introduced here.

Example 4

Preparation of glycated β-amyloid (AGE-Amyloid) (Loske et al., 2000; Munch et al., 1997)

Stock solutions of peptide were dissolved in deionized water at a concentration of 1 mg/mL. For AGE crosslinking experiments, they were incubated in 4 mL polypropylene tubes at a concentration of 250 μg/mL (60 μM) and 50 mM glucose in 50 mM sodium phosphate buffer, pH 7.9, at 50°C in the dark for 5 days. Sodium azide (0.01% w/v) was added to prevent microbiological growth. In long-term experiments, water was added every 12 hours to compensate for solvent evaporation. AGE-β-amyloid was then dialyzed against double-distilled water using Spectra/Por CE dialysis membrane (molecular mass cut off: 1000 Da), and then freeze dried.

Example 5

Treatment of AGE-β-amyloid or Native β-amyloid with the AGE-breaker Compound (Asif et al., 2000)

Two sets of experiments were prepared for each compound. Solutions for the first experiment contained 100 μM of β-amyloid in 50 mM Tris-buffered saline (TBS) pH 7.4, and 50 mM of one compound (the drugs were dissolved in DMSO and the solutions were prepared for dilution from this DMSO stock). The second set contained 100 μM of β-amyloid in TBS and 100 μM of one compound. The reactions were incubated at 37°C for 24 hours without stirring

(stagnant assay). Control experiments were prepared accordingly except that no AGE-breaker compounds were added to the tubes. The same protocol was used for both native and glycated β-amyloid peptides.

Example 6

Thioflavine T (ThT) Fluorescence Assay (Tjernberg et al., 1999)

The incubated samples are vortexed and 40 μL aliquots are withdrawn and mixed with 960 μL of 10 μM ThT in 10 mM sodium phosphate-buffer. Fluorescence measurements were taken with excitation of 437 nm and emission at 485 nm. Slit widths are set to 5 nm.

Example 7

Electron Microscopy

Preparations for the treated and untreated AGE-β-amyloid peptide aggregates were done according to Vasan et al. (1996). These preparations were examined on a transmission electron microscope.

Example 8

Cleavage of AGE Cross-links that Form *in Vivo*

AGE-breaker treatment *in vitro* can also decrease AGE cross-links that form *in situ* in rat-tail-tendon collagen of diabetic rats. For this study, diabetes was first induced in male Sprague-Dawley rats (Charles River, Wilmington, MA) weighing about 150-175 g by injection of streptozotocin (65 mg/kg, i.p.). Hyperglycemia was then confirmed 1 week later by plasma glucose measurement (≥250 mg/dL). Thirty-two weeks later, the rats are sacrificed and collagen was isolated from the tail tendon of diabetic and normal controls as described by Kochakian et al. (1996). Tail tendons were dissected free of adhering tissues, washed thoroughly in PBS containing protease inhibitors (1 mM each of EDTA, PMSF, iodoacetamide and benzamidine hydrochloride), patted dry onto a paper towel, rolled into a ball, freeze dried, and stored at -20°C in sealed containers until used.

Example 9

Treatment of Rat Tail Collagen with the AGE-breaker Compound

Representative samples of tail tendon collagen were pulled from its bulk and were cut approximately 20-25 mm in size. The samples were then placed inside 1.5 mL microfuge tubes and suspended with 1 mL of the desired concentration of the AGE-breaker compound in PBS buffer (pH 7.4) containing 0.02 g/L NaN_3. Untreated control tubes include tail tendon collagen and PBS buffer only. The tubes were incubated at 37°C for 24 hours. After incubation, the tubes were centrifuged at 10,000 rpm and the supernatants discarded. The collagen samples were rinsed with PBS, vortexed thoroughly, centrifuged briefly, and the supernatant discarded. This rinsing was repeated twice. On final rinse, the supernatant was discarded and the tubes inverted for one minute for the samples to air dry. These collagen samples were used immediately in the acid solubility and digestion studies.

Example 10

Tendon Collagen Solubility in Weak Acid (Sajithlal et al., 1998)

For determination of the amount of acid-insoluble collagen in samples treated and untreated with the AGE-breaker compound, 5 mg aliquots of dried tail-tendon collagen from diabetic and non-diabetic rats, all in duplicates, were added to 2 mL of 0.05 M acetic acid and stirred at 4°C for 24 hours. The mixture was homogenized in a polytron homogenizer and stirred for an additional 24 hours at 4°C. The suspension was then centrifuged at 9000 x *g* for 60 minutes at 4°C. The collagen in the clear supernatant was defined as the acid soluble collagen, and the gel-like pellet as the acid insoluble collagen. The pellet was lyophilized and weighed, and the percent acid insoluble collagen was calculated as: 100 x (lyophilized weight of pellet/original weight of tail tendon collagen). Percent increase in solubility was calculated as: 100 x (weight of acid insoluble collagen of untreated diabetic collagen - weight of acid insoluble collagen of treated diabetic collagen)/weight of acid insoluble collagen of untreated diabetic collagen.

Example 11

Total Pepsin Digestion Assay (Stefek et al., 2000)

Ten milligrams each of collagen samples from diabetic and non-diabetic tail tendons treated and untreated with the AGE-breaker compounds as described above were vortexed in 1 mL of freshly prepared pepsin (50 μg/mL in 0.5 M acetic acid) for 24 hours at 37°C. Following digestion, the samples were centrifuged at 3,000 rpm for 15 minutes. The clear supernatant containing digested collagen was collected and used for collagen-linked fluorescence. One hundred μL of supernatant were mixed with 900 μL of 200 mM phosphate buffer (pH 7.5), and excitation and emission fluorescence were recorded on a Hitachi F-2000 fluorescence spectrophotometer to determine wavelength values of maximal excitation and emission. Fluorescence of the samples was quantified at 365 nm excitation and 418 nm emission. All fluorescence values were corrected for fluorescence of the pepsin in phosphate buffer and expressed as arbitrary units per micromoles of hydroxyproline content of the collagen sample. The hydroxyproline content of each collagen sample was measured following acid hydrolysis, using a microassay method as described (Creemers et al., 1997). Percent decrease in fluorescence was calculated as: 100 x (fluorescence/μmol hydroxyproline of untreated collagen - fluorescence/μmol hydroxyproline treated collagen)/fluorescence/μmol hydroxyproline of untreated collagen.

Example 12

Papain Digestibility Assay (Verzijl et al., 2000)

Collagen-linked fluorescence of tail collagen of diabetic and non-diabetic rats treated and untreated with AGE-breaker compounds were measured as follows: about 5 mg of each collagen were digested for 2 hours at 65°C with 2.5 units/mL of papain in 500 μL of papain buffer (50 mM phosphate buffer (pH 6.5), 2 mM L-cysteine and 2 mM EDTA). Digests were centrifuged at 10,000 rpm for 60 minutes at 4°C, and the supernatant separated from the pellet. Fluorescence measurements at excitation 370 nm and emission 440 nm were performed as described above. Aliquots of the supernatant digests were also subjected to acid hydrolysis followed by hydroxyproline measurements. The results were expressed as fluorescence units per micromole of hydroxyproline content of each sample. Percent decrease in fluorescence was calculated as above.

Example 13

Acid Hydrolysis and Hydroxyproline Measurements

Aliquots (100 μL) of the pepsin or papain digests were hydrolyzed with 6 N HCl in 12 x 35 mm TFE-lined screw cap tubes (Fisher Scientific Co., Pittsburgh, PA). The tubes were autoclaved in a steam sterilizer at 250°F for 3.5 hours. The samples were taken to dryness using a Savant Speed Vac concentrator with heat, and stored at 4°C until assayed. The dried samples were rehydrated with 200 μL deionized water, and aliquots were assayed for their hydroxyproline content in a 96-well microtiter plate as described by Creemers et al. (1997).

Example 14

Determination of Cleavage of IgG-AGE Cross-linked to the Rat RBC Surface Using an Anti-IgG ELISA Assay

IgG cross-linked to the RBC surface was determined with an anti-IgG by a modification of the method described by Vasan et al. (1996). Briefly, heparinized blood was drawn from the tail vein in capillary tubes, inverted several times, then centrifuged at 200 x g for five minutes at room temperature. RBCs were washed three times with PBS in 0.5 mL microfuge tubes and packed with a final centrifugation at 500 x *g*. Red cells were diluted at 1:10 to 1:100 in Dulbecco's Modified Eagle's Medium that is normal for glucose. Experimental compounds were added at desired concentrations and incubated at 37°C in a CO_2 incubator for 24 hours in sterile conditions. Control incubations contained RBCs and PBS alone. After incubation, RBCs were washed three times in PBS and packed cells diluted 1:200 to 1:500. The RBC suspensions were gently vortexed and 50 μL aliquots added to 450 μL of a polyclonal rabbit anti-rat IgG conjugated to alkaline phosphatase (diluted 1:2500 in PBS). The tubes were then incubated at room temperature for 2 hours, then the RBCs washed three times with PBS, once with Tris-buffered saline (50 mM Tris, pH 8.0), and 0.5 mL to 1 mL p-nitrophenyl phosphate substrate was added (1 mg/mL with 2 mM Mg^{2+} in 0.1 M diethylamine buffered saline, pH 9.5), vortexed and incubated 30 minutes at room temperature. The RBCs were pelleted and the supernatant was read at 410 nm in either a conventional spectrometer or an ELISA reader. Blank readings were obtained by incubating tubes without cells.

Example 15

Data Analysis

Data are expressed as means ± S.D. or S.E.M. Unpaired students' *t*-test was used to compare differences between treated samples and control. A P value <0.05 was considered statistically significant.

Example 16

Results

The special ELISA method using AGE-BSA to crosslink with collagen-coated microplates is a suitable *in vitro* assay for rapid screening of crosslink formation and breakage. Using this technique, we observed that many of our previously reported inhibitor compounds are also capable of cleaving and breaking the AGE-BSA-collagen crosslinks (Figures 1A-C). Some of the compounds like LR20, LR23 and LR90 are more effective breakers at higher concentrations (Figure 1A), while others such as LR102, 5-ASA and metformin are more potent at lower concentrations (Figures 1B and 1C). We used these compounds to determine their effects on AGE crosslinks that form *in vivo* in tail tendon collagen of old diabetic rats (32 months old and blood glucose of >25 mmol/L).

The extent of AGE crosslinking of tail tendon collagen formed *in vivo* was assessed by acid insolubility and fluorescence measurements (Figures 2-5). Table 2 summarizes the effects of these compounds on rat-tail tendon collagen. All three tests produced varying results for the different compounds analyzed. In general, treatment of collagen with the compounds particularly at 1.0 and 10 mM concentrations resulted in increased collagen solubility and reduction of fluorescence associated with AGE crosslinks (Figures 2-5, Table 2). In all three tests, treatment of LR23 significantly increased solubility, and reduced the AGE-linked fluorescence of collagen of diabetic rats ($P<0.05$, Figures 2B, 3B and 4B). 5-ASA, which was found effective at low concentrations in the AGE-ELISA test, only showed cleavage effects in the papain test at these concentrations (Figure 5). Nonetheless, the limited number of collagen samples (2-3 samples) used in these studies may have contributed to statistical non-significance of the results of the other compounds rather than to their actual performance.

The AGE-breaking effects of these compounds were further evaluated on IgG-AGE crosslinked to the surface of RBCs. When compared to diabetic controls, RBCs treated with the

Table 2
Summarized Data on the Effects of
AGE-breaker Compounds on AGE Crosslinks that Form In Vivo

Compound	Acid Solubility Test (% increase in solubility)	Papain digestion Assay (% decrease in fluorescence)	Pepsin Digestion Assay (% decrease in fluorescence)
LR20			
0.1 mM	1.5	18.3	7.1
1.0 mM	7.3	18.4	8.9
10 mM	24.0	24.3	27.8
LR23			
0.1 mM	18.3	16.7	7.3
1.0 mM	19.4	25.9	15.5
10 mM	32.7	47.2	18.7
LR99			
0.1 mM	1.6	23.5	9.8
1.0 mM	7.3	35.9	16.1
10 mM	16.0	63.6	12.6
LR102			
0.1 mM	11.3	21.2	12.9
1.0 mM	18.1	22.8	23.8
10 mM	24.2	52.2	37.3
5-ASA			
0.1 mM	0	1.0	4.7
1.0 mM	5.7	17.3	12.1
10 mM	12.1	17.3	21.1
Metformin			
0.1 mM	0	3.5	3.1
1.0 mM	9.4	16.4	7.5
10 mM	10.3	19.2	12.7

All Values Are From Collagen Treated with the Compounds Relative to Untreated Collagen of Diabetic Rats.

compounds had less IgG-AGE bound to their surface (Figure 6). 5-ASA and LR102 treatments resulted in almost the same IgG-AGE content as that of non-diabetic control ($P<0.05$).

We also tested whether our compounds are capable of disaggregating both fibrillar native and glycated β-amyloid (AGE-βA) using the ThT binding assay and electron microscopy. Results of the ThT assay clearly confirmed the efficacy of the LR90, LR102 and 5-ASA on disaggregation of fibrillar forms of both native and glycated β-amyloid. Similarly, electron microscopic examination of the preparations of β-amyloid fibrils treated and untreated compounds revealed marked differences in the fibrillar form of the β-amyloid aggregates before and after treatment with the AGE-breakers. In control (untreated) preparations, β-amyloid shows dense fibrillar aggregate. In contrast, fibrils are less dense and non-uniform on the β-amyloid treated with an AGE-breaker. These results suggest that our novel AGE-breaker compounds have the ability of disaggregating the β-amyloid fibrillar structure.

Using the AGE-BSA-Collagen ELISA method, we found that many of our inhibitor compounds can also cleave and break AGE crosslinks. Many of them exhibited dose-dependent AGE-breaking activities, and a few like 5-ASA and metformin, are highly effective at low concentrations. Interestingly, we found 5-ASA to break AGE-BSA crosslinks even at 20 μM. This characteristic of 5-ASA may be one of the reasons this drug is effective in the treatment of "ulceritis colitis" and Crohn disease. Furthermore, 5-ASA may have some effects on reducing damage of β-amyloid content of Alzheimer plaques. Data on β-amyloid tests (performed at the Picower Institute for Medical Research in New York) revealed that this compound can disaggregate fibrillar forms of both native and glycated β-amyloid. Finally, this drug may have beneficial effects in reversing AGE crosslinks in rheumatoid arthritis, where accumulation of AGE in the collagen and an immunological response to IgG damaged by glyoxidation (AGE-IgG) has been reported recently (Lucey et al., 2000). Results of the IgG-AGE test indicated that 5-ASA treatment can significantly reduce IgG-AGE on the surface of RBCs.

The AGE breakers developed in our laboratory were effective in cleaving AGE crosslinks in the tail of diabetic rats as demonstrated by acid solubility and fluorescence measurements after pepsin and papain digestion. Furthermore several of the compounds were capable of breaking IgG-AGE crosslinks on the surface of red blood cells, as well as disaggregating both fibrillar forms of both native and glycated β-amyloid. Among the LR series of compounds, we found LR-23 and LR-102 as the most effective AGE-breakers. Metformin, a highly popular drug in the

treatment of Type 2 diabetes, which we previously reported to inhibit AGE formation, also showed moderate AGE-breaking properties. Thus, it is conceivable based on our results that compounds with different functional groups can cleave and break AGE crosslinks.

While the invention has been disclosed in this patent application by reference to the details of preferred embodiments of the invention, it is to be understood that the disclosure is intended in an illustrative rather than in a limiting sense, as it is contemplated that modifications will readily occur to those skilled in the art, within the spirit of the invention and the scope of the appended claims.

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